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STUDIES FOR STUDENTS.

PROPOSED GENETIC CLASSIFICATION OF PLEISTOCENE GLACIAL FORMATIONS.

Pleistocene formations that are not either directly or indirectly of glacial origin are not embraced in the classification herewith proposed.

There are at least three appropriate modes of classification of the Pleistocene glacial formations:

(1). A classification based upon the structural characteristics of the deposits.

(2). A classification based upon the origin of the formations.

(3). A classification based upon the time relations of the deposits.

Only the second will be here considered. A purely structural classification has an indispensable value, and is a fit subject for more and more critical consideration as our knowledge of the glacial formations increases. The classifications of the past will doubtless continue to need extension and more precise definition as glaciology advances. Nevertheless, our structural classifications do not seem to be so lacking in exhaustiveness, nor so defective in discrimination as our genetic classifications, and as time will not permit an adequate treatment of the three forms of classification, it has seemed best to pass the first by with a mere mention.

A chronological classification of the Pleistocene formations possesses the highest interest and constitutes one of the two great goals sought by glaciology. One of these is to ascertain how the formations were produced, the other, the times and sequences of their production. But it is too early yet to fix upon a satisfactory chronological classification. The data are not yet sufficiently gathered nor have they been tested with sufficient severity, to admit of satisfactory correlation of the successive glacial stages even within the limits of a single province. How much less, then, those of different continents. While recognizing, therefore, the supreme interest that attaches to a chronological classification, I am impressed with the feeling that it is best to postpone a formal attempt to establish such a classification until the data shall be more adequately developed. It is believed that the development of a more satisfactory genetic classification will be a step toward a more satisfactory chronological classification.

The following outline is submitted for discussion:

Six general classes are proposed.

A. GENERAL CLASSES.

I. *Formations produced by the direct action of Pleistocene glaciers.*—As very much of that which is commonly embraced, for convenience, under the general phrase *glacial formations* is not the direct and simple product of glaciers, but springs in part or in whole from accessory agencies, it is thought serviceable to discriminate the simple from the complex formations. In this classification glaciers are assumed to be the primary and chief agency in the production of the formations classified, but the secondary and associated agencies are very important, and often the final expression of the deposits is due chiefly, and sometimes wholly, to these auxiliary agencies.

II. *Formations produced by the combined action of Pleistocene glaciers and accompanying glacial drainage.*—All of the ice of the glaciers except that portion which was transformed into vapor passed away in the form of glacial waters, and to this there was added the rain precipitated upon the glacial expanse. The combination of the work of this large volume of water with that of the ice gave rise to results which neither the ice alone nor the water alone could accomplish. These constitute a distinct class of deposits.

III. *Formations produced by glacial waters after their issuance from Pleistocene glaciers.*—While the glacial waters were acting on the glacier, or more especially in tunnels within or under the glacier, they were constrained by the presence of the ice walls and forced into modes of action that they would not have assumed of themselves on free and open surfaces of the land. The formations of free glacial waters after their issuance from the ice are thus distinguishable from the confined glacial streams of the ice-body itself. The products of glacial waters after their issuance differ from the products of ordinary surface waters in the fact that they were overloaded with detritus in an extraordinary and peculiar way, and in the fact that this detritus differs from ordinary land waste. This difference furnishes one of the most valuable criteria in the discrimination of Pleistocene formations.

IV. *Formations produced by floating ice derived from Pleistocene glaciers.*—Assuming that the greater mass of the glacial deposits of Pleistocene age were formed by the primary agency of glaciers, it nevertheless remains important to distinguish the secondary products that were formed through the agency of floating ice derived from these glaciers. Just as the waters from the melting glaciers bore away and deposited a certain constituent of the material that had been wrought at first hand by the glaciers, so icebergs bore off and deposited in a fashion of their own another portion. The two classes are secondary and dependent upon the original glacial action, and some of the characteristics of the material must be sought in the original glacial action, but in their final stages the deposits take on character of their own.

V. *Formations produced by shore ice and ice-floes due to low Pleistocene temperature but independent of glacial action.*—The presence of the great ice sheets and the glacial conditions that produced them appear to have given rise to a class of independent ice deposits that may fittingly be put in this classification. These are believed by some writers to attain great importance. Whatever their extent, they need to be scrupulously discriminated from the products of both glaciers and glacier-derived icebergs.

VI. *Formations produced by winds acting on Pleistocene glacial and glacio-fluvial deposits under the peculiar conditions of glaciation.* —It is not unreasonable to suppose that the tracts bordering the great glaciers, especially those recently abandoned by them, were exposed to very effective wind action. The differences of temperature between the ice-clad fields and the adjacent ice-free lands may be supposed to have induced strong wind currents. Between their strength and the facilities offered for their action by bare surfaces of recently-formed incoherent material, there is ground for the belief that æolian deposits of more than usual magnitude and of peculiar characteristics were formed. So also, it is highly probable, if not certain, that some of the rivers of glacial times were accompanied by broad flats which they had themselves built up, and which they alternately flooded and left exposed, and that here the winds found a special field of effective action. Such æolian formations as resulted from these agencies are probably not so important in themselves as in the erroneous inferences to which they are likely to lead, if unrecognized. Such wind-blown sands and silts might easily be borne up to high levels and lodge there. If these are attributed to water action (which seems the natural alternative) they lead to hypotheses of flood-heights or of submersion of much magnitude; and these lead on to other conclusions of much consequence. The recognition of the class, especially in framing working hypotheses and interpretations, is thought to have some importance.

With the foregoing general statements, we may turn to the more special consideration of the several classes indicated.

B. SUB-CLASSIFICATIONS.

I. *Formations produced by the direct action of Pleistocene glaciers.* —Under this head may be recognized three sub-classes:

1. Formations that gathered at the bottom of the glaciers.

2. Formations derived from material borne on the glaciers and within them (but not at their basal contact) and deposited at their margins, or let directly down by their melting, when stagnant.

3. Formations produced by the mechanical action of the edge of the ice.

1. It is believed that the base of the glaciers was the great seat of action; that here took place the disrupting of the material and the larger part of the rubbing, grinding and crushing to which it was subjected in transportation. All of this material, however, did not come to final rest beneath the ice. A portion of it was borne away by the glacial drainage, a portion was thrust up into the ice and borne along to its edge and there deposited as superglacial material, and a portion may have once been uncovered by the retreat of ice and have been subsequently plowed up by a re-advance and so have taken on a new form of aggregation. There is, therefore, a discrimination to be observed between material that was *produced* at the base of the glaciers and that which was finally *deposited* at their base. It is only the latter class that is included here. Of deposits originating under the ice the following sub-classes are distinguished.

(1). *Subglacial sheets of till.*—These constitute one form of ground moraines; the form which is perhaps most commonly recognized. There are to be embraced here those broad sheets of till which were spread out under the ice and left, on its retreat, as a blanket mantling the surface of the land. These sheets are not uniform in thickness nor universal in their presence. In this classification it has been thought best to separate all distinct and special forms of aggregation from the more nearly uniform sheets of till, and to place them in the following sub-class. This is done in the belief that the causes of these special aggregations were somewhat special and peculiar, and that these forms are worthy of distinction for working purposes until their final significance and classificatory value shall be determined.

(2). *Subglacial aggregations of till.*—These admit of subdivision into two varieties, between which there is no sharp dividing line and which are perhaps separated from each other genetically only by the degree of their development. These are

a. *Drumlins.*

b. *Aggregations not strictly drumloid in form.*

a. Of the drumlins, four sub-varieties may be recognized, and it may prove serviceable to distinguish these and treat them as distinct varieties until the mystery of the drumlin formation shall be solved and the importance, or otherwise, of these distinctions be determined.

(*a*) *Lenticular or elliptical hills.*—These are the typical variety of drumlins and consist of very remarkable aggregations of till in hills of dolphin-back form whose longer axes are two or three, or at most a few, times longer than their transverse diameters. The longer axis lies in the direction of glacial movement. This is the most familiar form.

(*b*) *Elongated ridges.*—These have the same constitution as the preceding and have similar terminal contours. The body of the hill is, however, elongated to the extent of two or three or occasionally several miles. These elongated ridges commonly lie parallel to each other, giving a markedly fluted character to the surface. They are thought worthy of being distinguished for the present, because the elongation of their forms may prove a significant feature, and lead to the recognition of some of the essential conditions of drumlin formation.

(*c*) *Mammillary hills.*—These have the same constitution as the previous types. but differ from them in the extreme shortness of the axis. This, in some instances, is scarcely longer than the transverse diameter. These are thought worthy of being distinguished, because they emphasize more than either of the preceding varieties the vertical element of the constructive process. I know of nothing more extraordinary in glacial formations than the building up of these domes to the height of 50 to 60 or more feet with such steep sides and on so circumscribed and so nearly circular a base. There are no cases, so far as I am aware, in which the base is strictly circular. There seems always to be an element of elongation in the direction of glacial movement.

(*d*) *Till tumuli.*—These are low mounds of more than usually stony material (so far as I have observed). They have not generally assumed the drumloidal curves of contour and profile, but their nature is such as to have suggested that they are the immature nuclei of drumlins. Further investigation is proposed, and they are here introduced tentatively.

b. There are several classes of aggregations of till that are not strictly drumloidal in form but which are thought to deserve recognition, for the present, as varieties, for their possible suggestiveness respecting the physical processes of subglacial accumulation.

(*a*) *Crag and tail.*—These embrace the well known accumulations of till in the lee of rocky crags or embossments.

(*b*) *Pre-crag.*—These embrace the less well recognized accumulations of till in front of crags or embossments of rocks. These two forms may co-exist in connection with the same protuberance of rock and may coalesce. From this has arisen the suggestion that their coalescence might initiate a drumlin. In support of this, it is cited that many drumlins have a core or pedestal of rock. Against this is cited the fact that many drumlins have no such nucleus of rock so far as observation can discover.

(*c*) *Veneered hills.*—These are hills of rock, coated somewhat uniformly with till, the surface conforming approximately to that of the underlying rock. These differ from the crag-and-tail and pre-crag accumulations in the genetically significant fact of a much more uniform distribution of the till over the rock embossment and in the subordination of veneering to the pre-existent contour rather than the formation of a new contour.

(*d*) *Till billows.*—There is a class of drift accumulations which take on a billowy surface. They differ from the drumlins in their want of conformity to axes lying in the direction of the drift movement. The drumlins are also usually separated from each other by low flat ground. The till billows, on the other hand, are arranged more closely together, are disposed more irregularly, and are connected with each other by saddles or cols. Between these billows are frequent undrained basins. The type, it will be observed, graduates into, if it does not strictly belong to, the class designated below as submarginal moraines. Tracts of these till billows are usually distributed parallel to the margin of the ice, and to that extent conform to the habit of terminal accumulations. I have thought that they might be an intermediate form between submarginal moraines and drumlins, but, while they unquestionably graduate into the former, I have never observed their graduation into the latter. It seems, therefore, probable that they should be removed from this division and placed below.

(*e*) *Irregular till hills.*--Besides the above forms which show a tendency to some definite law of development, there is a considerable class of aggregations of till that seem to pay no respect to laws of symmetry or to systematic principles of growth. At present no classification seems tenable except one based upon their very irregularity.

(3). *Submarginal ridges of till parallel with the ice border.*—Both the till sheets (1) and the subglacial aggregates (2) that have been described above occupy territory extending for considerable distances back from the border of the ice, indeed, ideally the first class may be regarded as covering the entire territory occupied by the ancient glacier. On the contrary, the ridges of till here considered lie along what was the immediate border of the ice at certain of its stages. They are thought to have been formed under the edge of the ice, but it remains to be determined to what an extent they were accumulated under the immediate border of the ice and to what an extent they were deposited at the distance of one, two, or three miles from the precise edge of the glacier. It does not seem at present possible to determine, or at least it does not seem to have been determined, whether the whole of the accumulation was built up simultaneously throughout its entire breadth, or whether the outer portion was accumulated under the immediate edge of the ice and the inner portions built up a little later in like manner under the edge of the ice when it had withdrawn somewhat. These ridges are from one to a few miles wide, are composed essentially of till (though assorted material may form a greater or less constituent), possess in the main a gently flowing contour which distinguishes them from the rougher ridgings and sharper contours of frontal moraines formed by the mechanical thrust of the ice, or by the dropping of superglacial material at its edge.

(*a*) *Submarginal or lodge moraines* (*a variety of terminal moraines*).—The most important form falling under the above head may be designated submarginal or lodge moraines. They are designated submarginal, not so much because they are believed to be formed near the edge of the ice and not absolutely at its edge, as because they are believed to be formed *under* the margin of the ice. Three varieties of moraines, all of which may be called terminal, are recognized, being produced in three distinct ways. The first are formed from material borne on or in the ice (the latter being brought to the surface by ablation before reaching the edge) which is dropped at the terminus of the ice and which, when the ice remains stationary for a sufficient period, grows into a bordering ridge. These may be given the rather homely but expressive name *dump moraines.* The second is formed by the mechanical thrust of the ice when it advances against any incoherent material that lies in its path. These may be designated *push moraines.* The third variety consists of that under consideration, and which may be designated *lodge moraines*, from the conviction that the material, instead of being carried or pushed or dragged forward to the extreme edge of the ice, is permitted to lodge under its thin border, and constitute a submarginal accumulation. The lodge moraine is not in its nature or material radically different from the ground moraine which lodged farther back from the edge of the ice, and constitutes the subglacial till sheet. It differs from it, perhaps, only in the fact that the thinned and weakened edge of the ice presented conditions specially favorable to deposition, and that, as a result, a thickened belt of drift formed under the border of the ice when it remained approximately stationary for a sufficient period and took on the special billowy contours above described. The submarginal moraines were doubtless subjected to more or less mechanical action of the ice as it oscillated forward and backward. This action is thought to have been of the nature of an over-riding or an over-sliding of the ice rather than of a pushing or plowing up by the edge of the ice. It is my growing conviction that this form of the terminal moraine is the predominant one in the great American glacial field. I incline to the opinion that the broad complex tracts of thickened drift that mark the border of the ice sheet at several of its stages were chiefly formed in this submarginal way, and that, while there is usually present a constituent dropped from the surface of the ice and a constituent formed by the mechanical thrust of the ice, the great mass of these moraines, in general, accumulated by lodgment under the border of the ice but near its edge.

(*b*) As only those ridges which have some measure of persistency and which mark notable stages of the ice action should be formally designated terminal moraines, it seems advisable to recognize under a different head local ridges of till arranged transversely to glacial movement. These are to be contrasted with the drumlins which are elongated ridges of till whose axes lie in the line of glacial movement. These transverse local ridges are in some cases perhaps of the same nature as the submarginal moraines except that the action was limited. But for the greater part they may be presumed to have sprung either from exceptional conditions of accumulation, which led to exceptional deposition when the force of the ice was weakened, or to exceptional conditions favorable to deposition, the conditions in both cases determined by local agencies. They are thus distinguished from the products of those general agencies that produced the persistent submarginal moraines.

2. *Formations derived from material borne on the glaciers and within them* (*but not at their basal contact*) *and deposited at their margins or let directly down by their melting when stagnant.*

(1) *Dump moraines* (*a variety of terminal moraines*).—In various well known ways a certain amount of material finds lodgment on the surface of a glacier, and a certain additional amount becomes incorporated within its body. Leaving out of consideration such part of this as finds its way to the bottom, both the englacial and superglacial material is carried

forward and by ablation is at length brought to the surface of the ice and is carried on to its edge and dropped there. If the material is considerable and the border of the ice remains stationary for some time, notable accumulations may result in the form of border ridges constituting the variety of terminal moraines designated as dump moraines. When the englacial and superglacial material is inconsiderable in quantity the deposit may not amount to a ridge but may yet constitute a very definite and distinctive belt of material. The bowlder belts of several of the interior states are classed here. They cannot be said to be moraines in so far as that term implies ridging, but they are terminal border deposits that have much the same significance as terminal moraines and belong to the same general genetic class.

(2) *Englacial or superglacial till* (*"upper till"*).—When this englacial and superglacial material is let down over the whole territory of the ice, either during its successive stages of retreat or by being let down directly through the melting of the glacier when it becomes stagnant, it forms a superficial sheet quite analogous to the subglacial sheet already considered. This was some years ago designated "upper till" by Torrell, Hitchcock, Upham, and others, but because the term upper till was also used to designate a re-duplication of the subglacial till sheet by many other geologists, it was thought best to propose the term englacial or superglacial till. There still exist differences of opinion as to how much of existing deposits is to be referred to englacial and how much to subglacial till, and the criteria for discriminating between these are still under discussion, but the importance of the classification and the significance of its bearing upon the interpretation of glacial action and of glacial history seems beyond question.

(3) *Medial moraines.*—These familiar forms of glacial deposits do not call for remark, further than to note that they merge into dump moraines at the frontal edge of the ice and into superglacial till in cases in which they are let directly down by melting without being carried on to the terminus of the

glacier, and to observe further that they are very subordinate elements in the great Pleistocene glacial deposits.

3. *Products of the mechanical action of the edge of the ice.*

(1) *Push moraines (a variety of terminal moraines).*—The distinctness of this familiar variety will doubtless be sufficiently recognized without further remark. It is perhaps, however, worthy of note that two sub-varieties may be recognized based upon the glacial or non-glacial character of the material involved, since the latter variety is sometimes overlooked.

a. The first and common variety is formed of glacial material which may belong either to the subglacial, englacial, or superglacial variety, or it may be formed of glacio-fluvial or glacio-natant material. It must, however, be presumed to have been previously brought forward to the edge of the ice or beyond it, and to be thus subject to be plowed up or pushed up into ridgings by the thrust of the advancing ice, which is the essential factor in the formation.

b. The second variety embraces local material of any kind that lay in the path of the advancing edge of the ice and was pushed into ridges by it. It is non-glacial material except in the simple fact that it was ridged by ice action. It is entitled to be regarded as a moraine so far as its origin as a topographic form and a re-arranged formation are concerned. In other senses it is not.

(2) *Lateral moraines.*—These familiar forms need no discussion.

N. B. Interlobate moraines form a variety of terminal moraines and not, as is quite often stated erroneously, a variety of lateral moraines. They are produced along the line of contact of adjacent glacial lobes, but the direction of ice movement is perpendicular or approximately perpendicular to the moraines, and not parallel with them. The mode of ice action involved in their production, and the nature of the morainic aggregation resulting, is that of the terminal and not that of the lateral moraine. These interlobate moraines may belong to either of the three classes above designated—the dump, the push, or the lodge moraine, or they may be formed of the three combined.

II. *Formations produced by the combined action of Pleistocene glaciers and glacial drainage* (*assorted drift*).—The large amount of water derived from the melting of the ice, and the added amount contributed by rains, constituted a very important auxiliary agency and gave rise to much assortment and re-arrangement of the drift.[1]

Three classes of deposits may be discriminated, those that are the products 1) of subglacial streams, 2) of superglacial streams, and 3) of marginal waters.

1. *Deposits of subglacial streams.*

Subglacial waters may be classified in two groups, the first embracing those which flowed in well established tracts or tunnels formed in the base of the ice, the second embracing those which flowed in a more diffuse and irregular way under the ice. These appear to have given rise to corresponding deposits.

(1) *Osars* (*asar*) *or eskers* (*kames of many authors*).—It is thought to be now beyond question that trains of gravel accumulated in tunnels formed by subglacial streams and that these, on the disappearance of the ice, formed ridges. The course of these seems to have been conditioned partly by the slope of the land and partly by the direction of glacial movement. They are best developed where these approximately coincide. It can scarcely be said, however, that osars are limited to such coincidence. The more extensive, branching and typical forms were probably also conditioned by stagnant or approximately stagnant states of the ice in its vanishing stages. The Scandinavian term *asar* seems entitled to precedence both because these remarkable forms are typically developed there, and because they first received notable attention there. The term *eskers* is coming to be used somewhat freely by many American writers as a synonym and is preferred by some for phonic reasons, while the term *kames* is being used for a cognate variety of gravel accumulations, to

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[1] It is to be noted that only that assortment of the drift which was *contemporaneous* with the ice epoch and connected with the ice action is here taken into consideration. Modifications of the drift that took place subsequent to the disappearance of the ice, or independent of it, belong to a class quite distinct from that under discussion here.

be mentioned below. Whatever the terminology, it seems important to distinguish the long branching gravel ridges that represent the longitudinal drainage of the ancient glaciers from those gravel accumulations that are associated with terminal moraines, and that appear to be the debouchure deposits of glacial waters. A variety of osars or eskers may have been produced by superglacial streams, as will be recognized below.

(2) *Simple tracts or patches of drift formed by subglacial drainage.*—Thin sheets and lenses of sand and gravel in the midst of subglacial till are common phenomena and, while they may in many cases be produced by streams running in tunnels which afterward shifted their position and left no other mark than these patchy deposits, it seems probable that many of these detached sheets and lenses were produced by a diffuse and local drainage developed by any one of several combinations of conditions while the ice was still present and continuing its deposition of till. Similar patches on the surface were perhaps produced in a similar way.

2. *Deposits of superglacial streams.*

For the most part superglacial streams, after short courses, descend through crevasses or moulins and become englacial or subglacial. This was doubtless true of the Pleistocene glacial streams, and the material which they bore along found its final deposition either in connection with subglacial streams or with the glacial waters after they had emerged from the ice. Nevertheless, there are two forms of deposition by superglacial streams that probably find some representatives among Pleistocene formations. The first embrace those which were carried along by superglacial streams that succeed in reaching the edge of the ice or a channel which they cut back into the margin of the ice. In the one case it probably took the form of delta cones, in the other of narrow ridges formed through the restraining aid of the channel walls. The other variety is presumed to have been formed from deposits which gathered along the course of superglacial streams and were let down by the melting of the ice after the glacier became stagnant, retaining essentially the form of their original accumulation in the superglacial channel, except so far as they were disturbed in the process of descent. Of these there are perhaps two varieties.

(1) *Superglacial osars (asar) or eskers (kames of some authors).* —Under this head are to be classed such channel-deposits as retained their elongated form and became ridges, and hence fall under the Scandinavian type. In the earlier studies of the subject a considerable number of specialists would have inclined to classify most osars under this head, but opinion appears to be inclining toward the reference of the greater part of the osar ridges to subglacial agencies.

(2) *Superglacial kames.*—Sheets or pockets of assorted material gathered on the surface of the ice were doubtless subjected to much disturbance and re-arrangement in the process of descent. The resulting deposits would constitute undulatory tracts of drift or groups of hillocks for which there is perhaps no specific name, but which may be thrown under the general class kames for the present.

3. *Marginal deposits.*

Under this class are embraced all those deposits of glacial streams that were made at the margin of the mer de glace, and whose forms were dependent upon the conditions that obtained at the margin. The following classes are recognized:

(1) *Kames.*—To this class I refer irregular heapings of assorted drift generally arranged in lines or tracts transverse to glacial movement. They are often closely associated with and merge into terminal moraines of till. Sometimes they largely constitute the terminal moraines, the action of glacial waters being so great as to assort nearly all of the material brought forward to the edge of the ice. In such cases the morainic factor (in the genetic sense) is found in the mechanical action of the ice in restraining the action of the waters, in controlling the nature of the heapings and in pushing of the accumulations, distorting and modifying them. Irregular heapings of assorted drift of this variety are not, however, wholly confined to border tracts, but occur irregularly distributed over the area abandoned by the ice.

They differ from the osar type in their marginal relation to the ice and their transverse arrangement. There is, however, a gradation between the two, and no sharp line of demarkation has yet been found; probably none exists. But there appears to be this important genetic difference: the typical kames appear to be the products of relatively active vigorous glaciers, while the typical osars appear to be the products of extremely inactive, if not stagnant, glaciers. This important difference of significance is thought to amply justify the recognition of the two classes whatever may be the difficulties in sharply separating them.

The difficulties of sharply discriminating between the osar type and the kame type are increased by the fact that there is a class of gravel ridges having forms precisely like the typical osars, that lie more or less transverse to the glacial movement. These yet await thoroughgoing investigation, but I incline to the belief that they are to be regarded as true osars, and that they were formed during the stagnant conditions of the ice just before its disappearance, their transverse course being due to the control of the underlying topography. It has been stated that the course of the osars was conditioned partly upon the direction of the ice movement and partly upon the topography of the land surface. In this instance, it appears that the land topography dominated the osar formation, and that the movement of the ice became uninfluential. In support of this view it may be added that some osars on reaching the border of the ice turn to a course nearly parallel with it.[1]

(2). *Osar (esker) deltas or fans.*—It appears that when the glacial streams reached the border of the ice sheet and were free from bounding ice walls, they spread themselves out widely and dropped a large portion of their burden in the form of deltas or fans. These are not uncommon in the interior as well as in Maine, where the osar phenomenon has its most remarkable development in America. These deltas are very significant both in respect to the method of formation of the osars and in respect to the position and restraining functions of the ice sheet at the time of their formation.

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[1] Dr. Lundbohm has directed my attention recently to the fact that this is a not uncommon phenomenon in Sweden, as shown by the geological maps of the Swedish Survey.

(3). *Overwash aprons.*—When terminal moraines grew to constitute notable barriers along the border of the mer de glace, and when the ice pressed against these moraines so as to obstruct the transverse flow of the glacial drainage along their inner border, the waters derived from the ice crept over the moraines in numerous small streams, which deposited gravel, sand, and silt on the outer flank of the moraine. These deposits are often distributed along the moraines for great distances and constitute a fringe of assorted material to which Shaler has given the apt name "apron." These constitute one of the most satisfactory demonstrations of the marginal character of the moraines and of the relations of the ice to them. The material varies widely in coarseness according to the conditions of formation, and a structural sub-classification may be based upon it embracing (*a*) gravel—(*b*) sand—(*c*) silt-aprons. Immediately next to the moraine the material is sometimes exceedingly coarse, constituting little less than a boulder belt. At the other extreme of the series the silt sometimes forms a clay deposit and sometimes it takes on that peculiar assortment which constitutes loess.

The class of aprons here described are dependencies of definite terminal moraines. There were, however, tracts of assorted material formed by waters outflowing from the ice where no definite terminal ridging took place. Such forms may be designated *outwash* aprons in distinction from *overwash* aprons. This class is usually made up of sand or silt. In the latter case there are gradations into the great flanking tracts of loess which appear to have arisen in the manner indicated on very low slopes with prevailing slack drainage.

(4). *Pitted plains* (*in part*).—Both the osar deltas and the overwash aprons are characterized in certain regions by a surface marked with numerous depressions, sometimes symmetrical (kettles), sometimes irregular, with undulatory bottoms and embracing knobs and sub-basins, giving the surface an expression resembling the kames. A part of these pitted plains seem to be intimately connected in origin with the ice edge and to be due to marginal conditions, among which it has been thought that the incorporation of ice fragments, the grounding of ice blocks, the movement of the ice edge, and the development of underground ice sheets were among the special agencies, but the full explanation of the pitted plains can scarcely be claimed to have been reached.

III. *Formations produced by glacial waters after their issuance from the Pleistocene glaciers.*

1. *By glacial rivers.*

One of the most familiar facts of glaciology is the detritus-laden condition of the icy streams as they issue from the body of an active glacier. A portion of this material is thrown down immediately at the margin under the special conditions there presented and constitutes the formations classified above, but the larger portion is borne onward to varying distances and deposited quite independently of the agency of the ice. Two varieties of this class of deposits are worthy of being specially recognized.

(1). "*Valley drift.*"—In those cases in which the previous surface agencies had developed a definite drainage topography, and in which the gradient was favorable, the detritus was borne down the valleys leading away from the ice border in trains of gravel and sand. As the glacial streams were usually greatly overloaded with detritus at the outset, they built up their valley bottoms by depositing material from bluff to bluff constituting a valley plain, out of which subsequently beautiful systems of terraces were often cut. The most notable class of this type consists of those gravel valley-plains which head in a terminal moraine or, more strictly speaking, in the overwash apron of a terminal moraine. Sometimes the apron gathers in for many miles on either side giving a very broad expanded head to the valley tract. As these valley tracts may head on successive moraines and may be traceable far down their valleys, they afford most admirable means of working out glacial history by determining the intervals between the successive moraines and the topographic conditions under which they were formed. As the gradient of the streams that formed these valley tracts may be estimated, they afford valuable criteria for determining the altitude and the attitude of the land at the time of their formation.

(2). *Loess sheets.*—The above valley tracts grade from the coarsest gravel through sand to the finest silt. So long as they are confined definitely to the valleys, a sub-classification of them on the basis of coarseness or fineness of material would be rather structural than genetic though carrying a genetic significance. But when the waters spread widely beyond the immediate vicinity of the valley and the material took on a peculiar and distinctive assortment, there seems to be sufficient ground for recognizing a second genetic class. The great tracts of fluvial loess (not all varieties of loess) are placed here. These are valley phenomena, in part. They have for their axes the great valleys of the region and their thickest deposits are along the valleys. They, however, spread widely over the adjacent country so that conjointly they mantle the whole region. They also coalesce with the great fringing sheets of loess that are classed above as outwash deposits. The class graduates into typical valley deposits on one side, into typical fringing deposits on another, and, apparently, into wind deposits of loess on a third side.

2. *By fringing lakes.*

This class obviously embraces deposits of suspended material brought out from the ice into bordering lakes by glacial streams and spread over their bottoms, being generally of the clayey type, sometimes bearing lacustrine fossils, sometimes not; sometimes commingled with stony material dropped by floating ice derived from the edge of the glacier, sometimes not, at least not in notable quantities, and always more or less commingled with wash from the adjacent land not covered by ice. Theoretically, the type is characterized by the peculiar border of the deposit next the impounding ice. Practically, this characteristic is not always readily demonstrable.

3. *By bordering seas.*

This class differs from the preceding in the fact that the waters were not impounded by the ice (as they usually, but not always, were in the preceding case), and in the fact that the deposits are commingled with oceanic sediments, marine fossils, and impregnated with saline waters, which may or may not have been wholly removed subsequently.

IV. *Formations produced by floating ice derived from Pleistocene glaciers.*

The type of this class is glacio-natant till, in which the constituents are identical with those of glacial till except when formed under the action of currents which induced secondary modifications. Two sub-classes are to be recognized :

1. *Local.*—In general these are lacustrine but may be oceanic. Commonly the deposits took place in glacier-fringing (usually glacier-formed) lakes and constitute only a secondary phase of glacier formation. In cases in which the ice entered an arm or bay, or even the border of the ocean, and the deposit took place in the immediate vicinity, the deposit remained essentially a local one. If marine fossils or marine sediments were commingled, or if the marine factor is for any reason regarded as important, a sub-classification distinguishing between lacustrine and marine glacio-natant local deposits is justified.

2. *Foreign.*—These are essentially marine glacio-natant deposits and are due to icebergs derived from distant glaciers bearing to the point of deposit material wholly of foreign origin. Among the genetic conditions involved in this case are the submergence of the land beneath the ocean at the time of the deposit and its subsequent elevation. Local lacustrine glacio-natant deposits may be formed at various heights above the ocean level and subsequently exposed by the drainage of the lake without involving oscillations of the crust or the sea level. In the case of the great lakes, iceberg material borne from one

side and deposited on the opposite and distant side might constitute a recognizable sub-class under this head. Such deposits have been described.

V. *Formations produced by shore-ice and ice-floes due to low Pleistocene temperature but independent of glacier action.*

1. *Shore ridges due to ice push.*—In northern latitudes the shore action of ice (not including icebergs) is very notably, producing shore ridges of unusual strength, configuration, and importance. It is held by some writers that much of the phenomena placed on the above classes is referable to this. Without conceding this, it seems beyond question that this class of deposits need special recognition in the study of the Pleistocene formations.

2. *Littoral deposits.*—If we confine the above class to those ridges which were pushed up on the shore above the reach of the waters, we need also to recognize a class which was deposited beneath the border of the body of the water. These differ from ordinary littoral deposits in the special contribution resulting from the ice action.

3. *Off-shore deposits.*—These embrace the material of the ice action of the shore borne back in suspension or by ice floes into still waters and there deposited. They must, in the nature of the case, very closely similate the formations produced by floating ice derived from glaciers.

VI. *Formations produced by winds acting on Pleistocene glacial and glacio-fluvial deposits under the peculiar conditions of glaciation.*

Recalling what was said under this head near the opening of this discussion, it may suffice here to simply indicate two classes that may be recognized under this head.

1. *Dunes.*—These differ in no important respect from ordinary dunes, except that the material is made up in part of grains formed by glacial grinding instead of disintegration and wave wear, and in their correlation with the ice border and the glacial waters that issued from it, rather than with the sandy shores of lakes and seas.

2. *Æolian loess.*—While the larger part of the loess found in

the glaciated region of North America is believed to be the product of glacial waters, it still remains, in my view, probable that certain parts of it were deposited by winds. This part is believed, in general, to have been derived from the water-deposited portion, but perhaps this is not universally true. Along the leeward side of the Mississippi river, for instance, we find dunes of sand and dune-like accumulations of loess that seem in both instances to have been derived by winds from the flooded flats of the river below. In like manner, there seems ground for the belief that in Pleistocene times, the glacial floods alternately extended and withdrew themselves, leaving great silt-covered flats exposed to wind action, and that from these silt was swept up and deposited over adjacent and perhaps somewhat distant highlands. It seems also not improbable that the conditions of the surface may have been such as to permit the lodgment of this more uniformly over the surface than is the habit with dunes. There seems ground for this in the distinction between the formation of dunes and the supposed deposits. Dunes are formed from sand driven along the surface by winds, but not in any notable degree carried by the winds in full suspension. The supposed silt deposits, on the other hand, are presumed to have been formed by silt borne in free suspension until, by contact with the earth, it was lodged. Such contact might obviously be widespread and the lodgment product might have a wide and measureably uniform distribution. While, therefore, coinciding with what seems to be the majority opinion among American geologists that the loess deposits of the glaciated region are chiefly water-lain, it appears to me prudent, if not important, to recognize the æolian class, and to search diligently for criteria of discrimination between the two classes.

The foregoing classification is consciously incomplete. In some instances the bases of distinction border closely upon the structural rather than the genetic, but it is believed that there is involved in every case an important genetic factor, though it may sometimes be most conveniently expressed in structural terms.

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